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ACCOUNTING FOR FISHING DAYS WITHOUT A FISHING SET IN THE CPUE STANDARDISATION OF YELLOWFIN TUNA IN FREE SCHOOLS FOR THE EU PURSE SEINE FLEET OPERATING IN THE EASTERN ATLANTIC OCEAN DURING THE 1993-2018 PERIOD

L. Guéry[1,2], D. Kaplan[2], C, Deslias[2], F. Marsac[2], F. Abascal[3], P. Pascual[3] and D. Gaertner[2]

SUMMARY

The time series of EU purse seine fleet catches per unit effort (CPUE) of yellowfin tuna (YFT) from the Atlantic Ocean were standardized using an extension of the Delta-lognormal GLMM to three components. The aim was to depict the trend in abundance for adult YFT observed in free schools (FSC). The originality of this work relied on the inclusion of i) null sets, considered as presence of YFT FSC, ii) fishing days without set, considered as absence of FSC, iii) EU fishing agreement in the exclusive economic zones driving EU purse seine fleet presence in these areas, and iv) time spent by centroid cell by boat by day to constrain detectability. Standardized CPUE for FSC was thus defined as the product of the number of set (positive and null) by spatio-temporal strata, the proportion of sets with large YFT (>10 kg) and the catch per large YFT set. To detect strata without sets, all activities recorded in captain logbooks were used for the period 1993-2018. This new standardization approach, therefore, represents a significant advance over previous efforts, though there are a number of avenues for future progress.

RÉSUMÉ

Les séries temporelles des captures par unité d'effort (CPUE) d'albacore (YFT) de l'océan Atlantique effectuées par la flottille de senneurs de l'UE ont été standardisées en utilisant une extension du GLMM Delta-lognormal à trois composantes. L'objectif était d'illustrer la tendance de l'abondance des albacores adultes observée en bancs libres (FSC). L'originalité de ce travail reposait sur l'inclusion des éléments suivants : i) opérations nulles, considérées comme la présence de YFT FSC, ii) jours de pêche sans opération, considérés comme l'absence de FSC, iii) accord de pêche de l'UE dans les zones économiques exclusives entraînant la présence de la flottille communautaire de senneurs dans ces zones, et iv) temps passé par cellule centroïde par bateau par jour pour limiter la détectabilité. La CPUE standardisée pour FSC a donc été définie comme le produit du nombre d'opérations (positives et nulles) par strates spatio-temporelles, de la proportion d'opérations avec de grands YFT (>10 kg) et de la prise par opération sur de grands YFT. Pour détecter les strates sans opérations, toutes les activités consignées dans les carnets de pêche des capitaines ont été utilisées pour la période 1993-2018. Cette nouvelle approche de standardisation représente donc un progrès important par rapport aux efforts précédents, bien qu'il y ait un certain nombre de possibilités de progrès futurs.

1 E-mail address of lead author: lorelei.guery@ird.fr
2 Institut de Recherche pour le Développement (IRD), UMR MARBEC, CS 30171, Av. JeanMonnet, 34203 Sete Cedex, France
3 Instituto Español de Oceanografía (IEO), Centro Oceanográfico de Canarias. Vía Espaldón, dársenapesquera, Parcela 8 38180 Santa Cruz de Tenerife, Spain

RESUMEN

La serie temporal de la captura por unidad de esfuerzo (CPUE) de la flota de cerco de la UE de rabil (YFT) del océano Atlántico se estandarizó utilizando una ampliación del GLMM delta lognormal a tres componentes. El objetivo era ilustrar la evolución de la abundancia de rabiles adultos observada en bancos libres (FSC). La originalidad de este trabajo se basó en la inclusión de (i) lances nulos, considerados como presencia de YFT FSC, (ii) días de pesca sin lances, considerados como la ausencia de FSC, (iii) acuerdos de pesca de la UE en las zonas económicas exclusivas que lleva a la presencia de cerqueros de la UE en estas zonas, y (iv) el tiempo pasado por celda centroide por buque por día para limitar la detectabilidad. Por lo tanto, la CPUE estandarizada para FSC fue definida como el producto del número de lances (positivos y nulos) por estrato espacial y temporal, la proporción de lances con rabil grande (>10 kg) y la captura por lance sobre rabil grande. Para detectar estratos sin lances, se usaron todas las actividades registradas en los cuadernos de pesca de los patrones para el período 1993-2018. Por consiguiente, este nuevo enfoque de estandarización representa un avance significativo con respecto a esfuerzos anteriores, aunque hay muchas vías para progresos futuros.

KEYWORDS

Abundance; CPUE standardization; Purse seiner; Spatial variations; Logbooks; Yellowfin tuna

1. Introduction

The goal of this paper is to develop yellowfin tuna (YFT, *Thunnus albacares*) indices of abundance derived from reported catches of EU tropical tuna purse seiners operating in the Atlantic Ocean, as part of the EU funded project Cecofad II[4]. This work thus aimed at developing standardised Catch per unit effort (CPUE) time series to be provided to ICCAT as an input for the stock assessment of YFT held in July 2019 in Abidjan. In this study we considered only sets of large YFT (> 10 kg) on free school (FSC) so as to capture the spawning-stock biomass of the population.

Interpreting changes over time in CPUE series as a trend in abundance has always been a major challenge for scientists working in stock assessment. In the case of the tropical tuna purse seiner fishery operating in the Atlantic Ocean, there are several factors affecting the CPUE-abundance relationship, such as the increase in individual fishing power of the vessel due to the implementation of new technologies, the change in the fishing grounds, or the adoption of the drifting fishing aggregative devices in the early 1990s (Fonteneau el al, 1999; Gaertner and Pallares, 2002). In addition because tunas are usually spatially structured in schools and in clusters of schools it is important to consider that any change in abundance may be influenced by the number (or density) of schools at sea, as well as by the size of individual schools (Fréon and Misund, 1999). To account for the presence of a large number of zero-catch fishing days, the delta-lognormal method (Lo et al, 1992) has commonly been used in a variety of fisheries, the specific index for a given year being the product of year average fitted values of the lognormal (for the positive CPUEs) and the binomial (for the proportion of days with catch) models.

With these consideratiuons in mind, Katara et al. (2016, 2017) developed a delta-lognormal GLMM approach with two sub-models: a binomial GLMM that standardises the probability of a positive set, and a lognormal GLMM that standardises catch conditional on the set being positive. In this approach, a positive set is taken to be a set with catch of the target species, so null sets are implicitly taken to indicate the absence of fish. However, bearing in mind the fact that null sets generally correspond to the presence of a fish school that simply avoided the net and that the abundance of large YFT may also be related to the number of free schools detected per unit of search time, we proposed in this paper a new modelling approach based on a Delta-lognormal GLMM with 3 components: (i) a Poisson first component modelling the density of free schools based on the number of sets (positive and null) per unit of boat searching time, (ii) a binomial second component modelling the fraction of free schools possessing large YFT based on the fraction of positive sets (i.e., sets with catch of any species; non-null sets) with catch of large YFT, and (iii) a lognormal third component modelling the size of free schools possessing large YFT based on catch of large YFT in large YFT positive sets. Along with the commonly used covariates relating to vessel characteristics and spatiotemporal variability, the originality of this work consists of the inclusion of i) null sets, considered as presence of yellowfin tuna FSC, ii) fishing days without sets, considered as absence of FSC, iii) EU fishing agreement data as drivers for fishing boat activity in exclusive economic zones (EEZ), and iv) time spent by cell by boat by day to constrain detectability. Standardized CPUE for FSC was thus defined as the product of the number of sets (positive and null) per unit search time, the proportion of positive (non-null) sets containing large YFT (> 10 kg) and the catch per sets of large YFT. To detect and include cells explored, but for which a set was not carried out, all activities recorded in the captain logbooks were used for the period 1993-2018. Due to the large number of candidate variables, a Lasso variable selection procedure has been used for the detection of the explanatory factors useful for the standardization of the CPUE of large yellowfin in free schools (Katara et al, 2016).

2. Material and Methods

2.1. Conventional fishing data

Logbook data for the French and Spanish purse seine fleets targeting tropical tuna in the Atlantic Ocean from 1993 to 2018 were analysed to derive the standardised CPUEs. The logbook databases are managed by the Tuna Observatory (Ob7) and the IEO for the French and the Spanish fleets, respectively. The raw logbook data (Level 0) produced by the skippers were corrected in terms of total catch per set (to account for the difference between reported catch at sea and landed catch) and species composition (based on port size sampling and the T3 methodology – see Pallarès and Hallier 1997) to generate the Level 1 logbook database used in this paper.

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[4] Catch, effort, and ecosystem impacts of tropical tuna fisheries (CECOFAD2); EASME/EMFF/2016/008 is a research project co-funded by the European Commission with participation of scientists from IRD, IEO, AZTI, CEFAS and MRAG.

The free-school sets (FSC) dataset, i.e. non-associated school sets and whales' sets, was used to derive CPUE for the adult fraction of the YFT stock, by selecting the commercial size categories 2 and 3 (> 10 kg).

The analysis was restricted to:

- The period 1993-2018 for FSC sets to be able to have the larger coverage of days without set reported
- The area defined by all grid cells where YFT of category 2 and 3 were fished for at least 5 years over a period of no less than 15 years, to avoid areas that are not routinely fished
- 1*1 degree cells without at least 20% of YFT category 2 & 3 were removed as well as 5*5 degrees cells occupied less than 50% to keep cells representative of YFT > 10 kg habitat (Figure 1)
- High seas and all EEZs
- Vessels with fewer activities than the 5% of the left hand distribution based on the cumulative number of days per boat (all activities confounded) were removed
- Entire days with at least one activity with problematic operations were removed
- All sets per boat and day were aggregated and attributed to the centroid of these set activities
- Distances between successive sets null-FSC/next-FSC for a boat is not significantly different from all other combinations: no need of buffer avoiding to count the same school several times
- Total number of sets per day per boat was filtered and days with unrealistic data were removed

2.2. Modelling approach

2.2.1. Delta-lognormal GLMMs

As mentioned in the Introduction section, delta-lognormal GLMMs were developed including three sub-models: a Poisson GLMM that standardises the number of positive and negative sets, a binomial GLMM that takes into account the fraction of positive sets with large YFT and a lognormal LMM to describe the catch conditional to positive set. Available variables are detailed in **Table 1.**

We performed the Poisson GLMM where the full model included the following fixed effects: fleet country, age of the vessel, number of sets on FOB, vessel storage capacity, year, quarter and 5ºx5º grid cell. The number of FOB sets per trip was included as a proxy for vessels' fishing strategy changes across time due to the increase of dFADs. The random structure of the model includes fishing access and a vessel unique identifier. The time spent by searching centroid by day was calculated as (sun set time – sun rise time) – (number of set*median of setting time) and was used as an offset.

Component 1:

num_sets_fsc ~ fleet country + age of the vessel + num_sets_fob + vessel storage capacity + year + quarter + cwp55_group + (1| numbat) + (1|eez:fishing_access) + offset(searching_centroid)

The full model for the binomial GLMM and the lognormal LMM included the following fixed effects: fleet country, vessel storage capacity, year, quarter, 5ºx5º grid cell. The random structure of these models included a vessel unique identifier. The number of positive sets was used as an offset.

Component 2:

yft_pos ~ fleet country + vessel storage capacity + year + quarter + cwp55_group + (1 | numbat) + offset(nb of positive sets)

Component 3:

log_capture ~ fleet country + vessel storage capacity + year + quarter + cwp55_group + (1|numbat) + offset(nb of positive sets)

GLMM tables and results are presented in appendices.

2.2.2. LASSO regression

For multidimensional data, variable or model subset selection through stepwise selection becomes problematic. The number of possible models grows exponentially with the number of predictors and renders computation infeasible. Moreover, when the number of observations is not much larger than the number of predictors, ordinary least squares may result in over-fitting. Penalized maximum likelihood methods allow regression modelling when the number of model parameters is high compared to the number of observations and prevent over-fitting (Tibshirani 1996). Models, consisting of all predictors, were fitted with LASSO, a popular technique that constrains (i.e. regularizes) the coefficient estimates. Technically, Lasso minimizes the usual sum of squared errors, with a bound on the sum of the absolute values of the coefficients (Tibshirani, 1996, 2011).

Model selection involved the use of the LASSO regression using algorithms that handle continuous explanatory variables (R package: glmnet; Friedman *et al*. 2009, 2010) and grouped covariates (R package: grpreg; Breheny and Breheny, 2018). Given a linear regression with standardized predictors *xi* and centred response values y_i for i=1,2, …, N and j=1,2, …, p, the glmnet algorithm estimates the regression coefficients $b=\{b_j\}$ to minimize:

$$\frac{1}{N}\sum_{i=p}^{N} w_i\, l(y_i, b_0 + b^T x_i) + \lambda\left[\frac{(1-a)||b||_2^2}{2} + a||b||_1\right]$$

where λ covers a range of values, l(y,η) is the negative log-likelihood contribution for observation i and a controls the elastic-net penalty (for lasso α=1). The tuning parameter λ is chosen through cross-validation.
The LASSO procedure was followed by backward model selection for both the random and fixed effects of the mixed models using AIC and BIC. Finally, the selected model was refitted as an unrestricted GLMM (R-package: lme4; Bates et al., 2014) but not with LASSO, as LASSO estimated coefficients are known to be biased (Friedman *et al*., 2001). Finally, the standardized CPUEs were fitted using estimated means.
All the statistical analyses were computed using the software R (v3.4.3; R Core Team, 2017).

3. Results

3.1. LASSO regression

Results are presented in **Table 3**.

3.2. Colinearity issues

Colinearity issues were tested with the package *pertub v2.10*. Some colinearity issues between some 5*5° cells and some factor levels were detected for the first Poisson component (**Table 2**). An attempt to solve these issues was to group the problematic cells.

3.3. FSC sets (1993-2018 period): Poisson GLMM (number of large-size YFT catch > 0 and = 0)

3.3.1. Diagnostics

Diagnostics are presented below (**Figure 2**, **Figure 3**, **Figure 4**).

3.3.2. Standardized time series

Standardized time series are presented by year-quarter (**Figure 5**) and by year (**Figure 6**).
We used the package *arm v1.10-1* (*sim* and *fitted* functions) to simulate posterior distributions and calculate confidence intervals.

3.4. FSC sets (1993-2018 period): Binomial GLMM (fraction of positive set with large YFT)

3.4.1. Diagnostics

Diagnostics are presented below (**Figure 7**, **Figure 8**, **Figure 9**).

3.4.2. Standardized time series

Standardized time series are presented by year-quarter (**Figure 10**) and by year (Figure 11).
We used the package *arm v1.10-1* (*sim* and *fitted* functions) to simulate posterior distributions and calculate confidence intervals.

3.5. Log-Normal GLMM (catch per hour conditional to YFT catch > 0)

3.5.1. Diagnostics

Diagnostics are presented below (**Figure 12**, **Figure 13**, **Figure 14**).

3.5.2. Standardized time series

Standardized time series are presented by year-quarter (Figure 15) and by year (Figure 16).
We used the package *arm v1.10-1* (*sim* and *fitted* functions) to simulate posterior distributions and calculate confidence intervals.

3.6. Delta lognormal GLMM approach

The product of the three sub-models described above provided the standardised CPUE time series for free school sets by quarter (Figure 17) and by year (Figure 18). We considered the three components independent and calculate confidence intervals with:

$$\mathrm{Var}(XY) = E(X^2Y^2) - (E(XY))^2 = \mathrm{Var}(X)\mathrm{Var}(Y) + \mathrm{Var}(X)(E(Y))^2 + \mathrm{Var}(Y)(E(X))^2$$

The formula was first applied to the product of the first (C1) and the second component (C2) than to the product of C1*C2 and the third component.

4. Discussion

In this paper we proposed a new approach for CPUE standardization for the tropical tuna purse seine fisheries to account for the hierarchical structure of the tuna free schools, for the non-randomised sampling and the numerous candidate variables linked to technological developments and evolving fishing strategies. A step forward compared to previous years was the inclusion of i) null sets, considered as presence of YFT FSC, ii) fishing days without set, considered as absence of FSC, iii) EU fishing agreement in the exclusive economic zones driving EU purse seine fleet presence in these areas, and iv) time spent by centroid cell by boat by day to constrain detectability.

Despite the significant improvements in this analysis with respect to prior work, there are a number of different avenues for further improvement. Among the most interesting and pressing are the inclusion of environmental covariates and further exploration of colinearity issues among covariates. Environmental variability is undoubtedly a strong driver of tropical tuna fisheries, and, therefore, the inclusion of environmental covariates in our models is desirable. Nevertheless, this is challenging because it is often not clear if an environmental covariate primarily drives abundance (and therefore should vary when predicting standardized CPUE values) or is simply impacting catchability (and therefore should be fixed at a standard value when making predictions). For example, mixed layer depth undoubtedly impacts primary production, which ultimately impacts tuna stock size, but it also, influences the depth distribution of tunas and therefore their accessibility to surface purse-seine gear. One potential approach to resolving this issue is to split environmental variability into long-term climatological variability and short-term anomalies, the first being associated with overall abundance in the area and the second being associated with short-term changes in catchability.

Another issue with including environmental covariates is that they are likely colinear with other spatial and temporal covariates due to strong seasonality in the tropical Atlantic Ocean. This issue has already been observed in existing models with some spatial 5x5 grid cells being colinear with certain seasons, preventing proper model convergence. We resolved this issue by regrouping grid cells colinear with different seasons into a single large grid cell that was no longer colinear with a single season, but this is an ad hoc approach that can likely be improved. A more objective solution would be to use principal component analysis (or more its generalization to a mixture of continuous and categorical variables, multiple factor analysis) to select a reasonable set of non-colinear variables before constructing GLMM models.

Acknowledgements

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Table 1. Available variables for the calculation of CPUE and the development of the standardisation models.

Variable	description
fleet country	France; Spain
numbat	Unique vessel identifier
Vessel storage capacity	In m^3
cwp55 grid cell	Reference grid of the fishing area at a 5°x5° resolution
Number of sets on FOBs	Resolution monthly per cell
Number of positive set	Number of positive sets per boat per day per centroid
Year	Year at which the fishing set took place
Quarter	Quarter of years
Age of vessel	Year – Year of vessel service
Economic Exclusive Zone	Identifiers of EEZs and the offshore area
Fishing access	Agreement between countries to fish in the EEZs
	EU fishing agreement in the different EEZ
Searching centroid	In h

Table 2. Exemple of colinearity diagnostic results between variables of the first Poisson component. Colomn II is the line number, rn and cn the level of the collinear variables and cc the correlation coefficient.

ll	rn	cn	cc
49	cwp55405020	intercept	1.0000000
98	cwp55405020	(Intercept)	1.0000000
142	cwp55400010	Pays4	0.7622394
192	cwp55400015	Age	0.6186074
1663	cwp55400020	Trimestre_de_peche2	0.6694931
1712	cwp55400020	Trimestre_de_peche3	0.5050325
1712	cwp55400020	Trimestre_de_peche3	0.5050325

Table 3. LASSO regression results for component 1 (a), 2 (b) and 3 (c)

(a) Variable	Coefficient
Lambda min = 0.001	
(Intercept)	-1.42 e+00
Pays	-1.55 e-01
Annee_de_peche	1.73 e-02
Trimestre_de_peche	-7.14 e-02
Cwp55	2.18 e-03
EEZ	-1.11 e-04
Nb_calees_bo	-8.54 e-01
Num_bat	-8.59 e-05
Capacité	.
Age	4.37 e-02
Acces_peche	-8.27 e-02
Temps_recherche	-8.73 e-01

(b) Variable	Coefficient
Lambda min = 0.0006	
(Intercept)	0.94
Pays	-0.06
Annee_de_peche	0.007
Trimestre_de_peche	-0.08
Cwp55	0.005
Num_bat	.
Capacité	0.009
Nb_calee_pos	0.01

(c) Variable	Coefficient
Lambda min = 0.0005	
(Intercept)	2.99
Pays	-0.08
Annee_de_peche	-0.01
Trimestre_de_peche	-0.06
Cwp55	0.01
Num_bat	-0.0009
Capacité	0.11
Nb_calee_pos	0.10

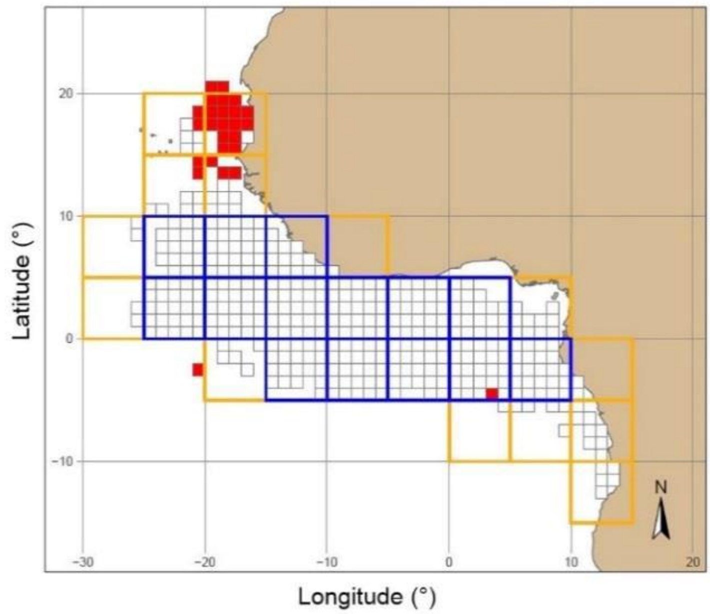

Figure 1. Study area with removed 1*1° cells (red) without at least 20% of YFT category 2 & 3 and 5*5° cells occupied less than 50% (yellow). 5*5 cells occupied more than 50% are shown in blue.

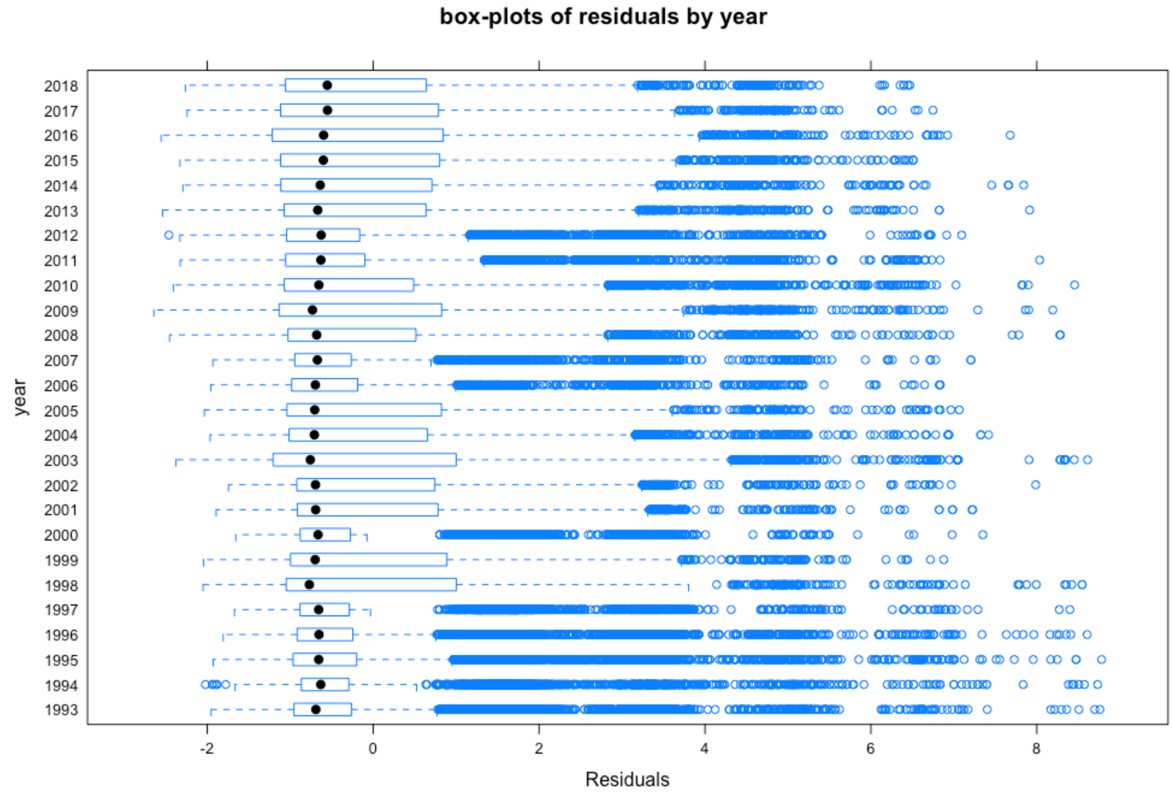

Figure 2. FSC sets - number of large-size YFT catch > 0 and = 0: box-plots of residuals by year

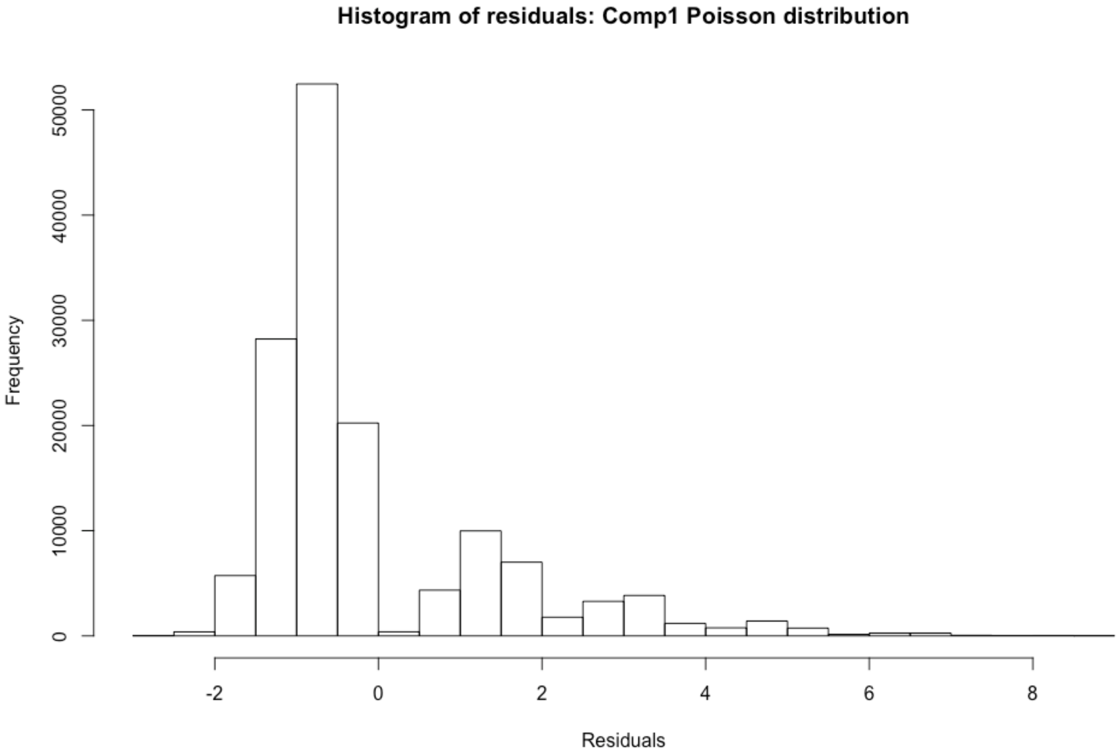

Figure 3. FSC sets – number of large-size YFT catch > 0 and = 0: histogram of residuals

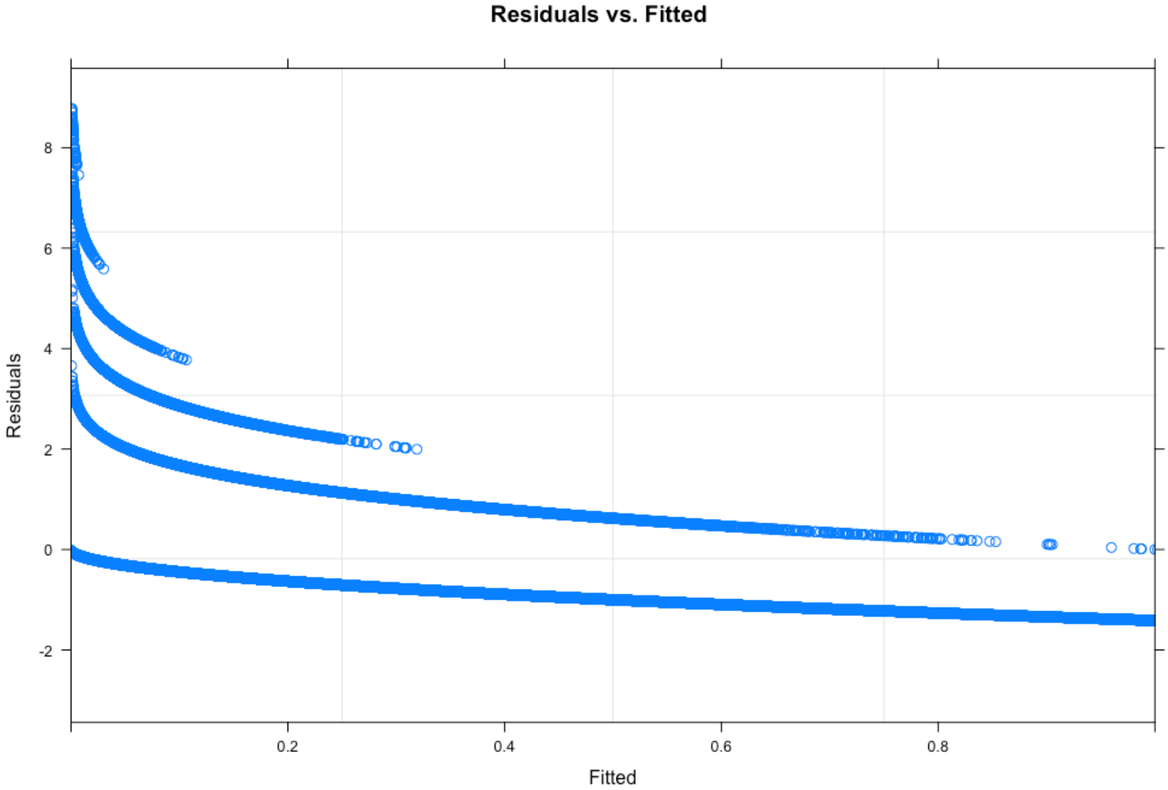

Figure 4. FSC sets – number of large-size YFT catch > 0 and = 0: residuals versus fitted

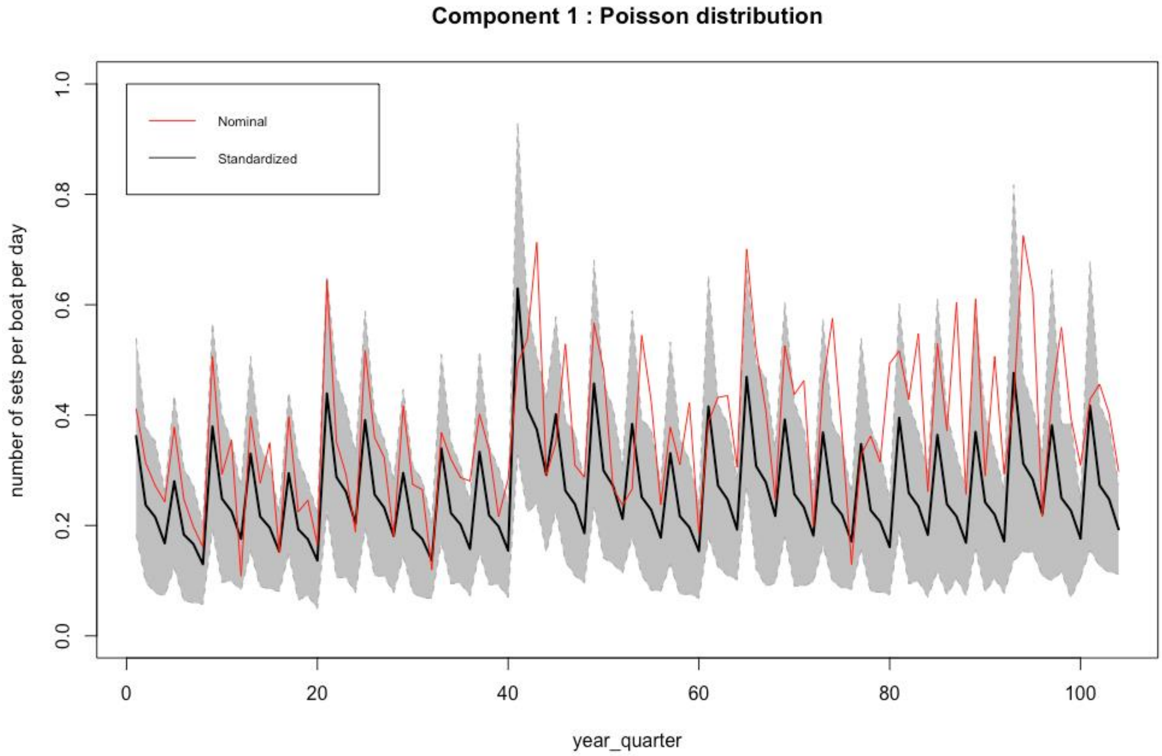

Figure 5. FSC sets – predicted number of large-size YFT catch > 0 and = 0: standardised time series by year-quarter (black) with 97.5% confidence intervals (grey) compared to nominal (red)

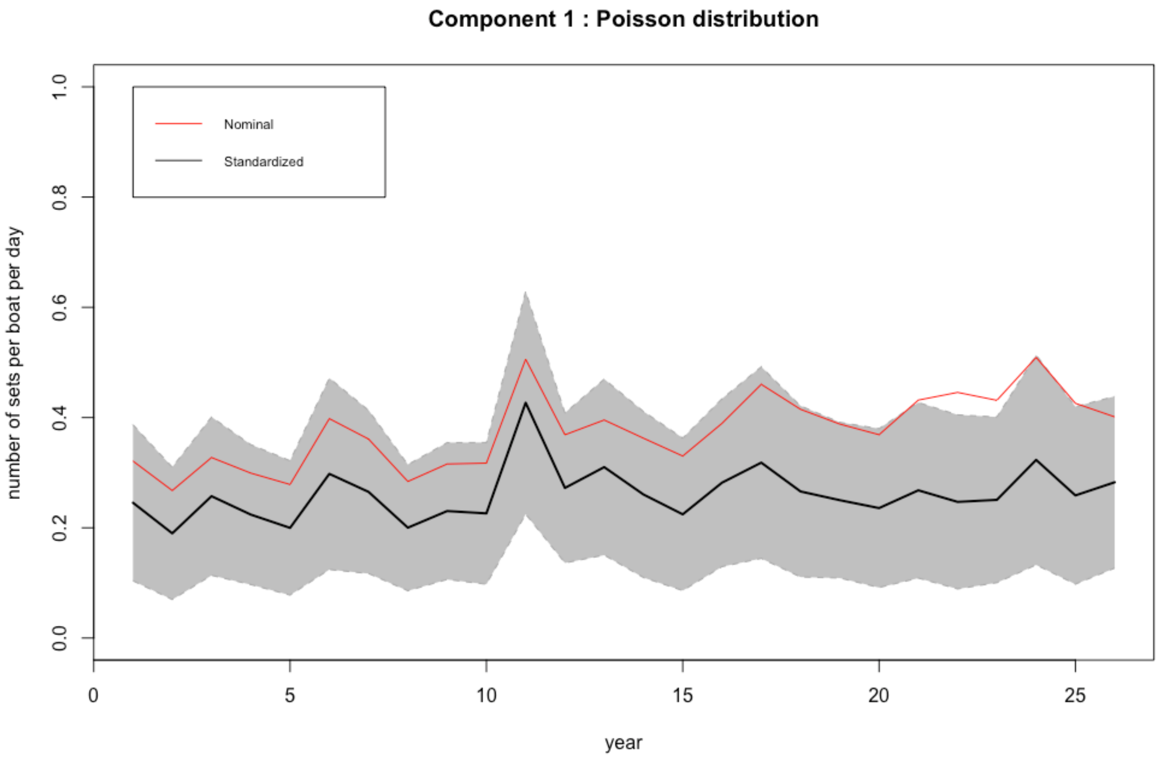

Figure 6. FSC sets – predicted number of large-size YFT catch > 0 and = 0: standardised time series by year (black) with 97.5% confidence intervals (grey) compared to nominal (red)

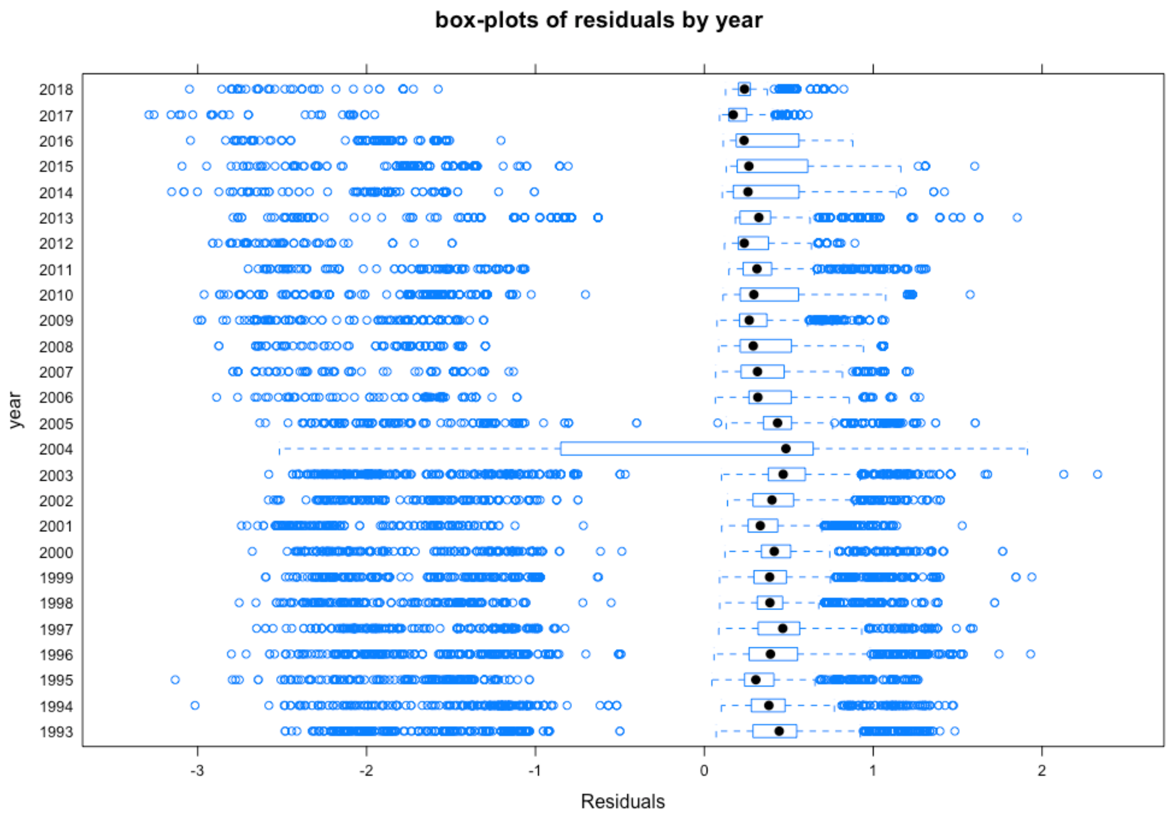

Figure 7. FSC sets - fraction of positive set with large YFT: box-plots of residuals by year.

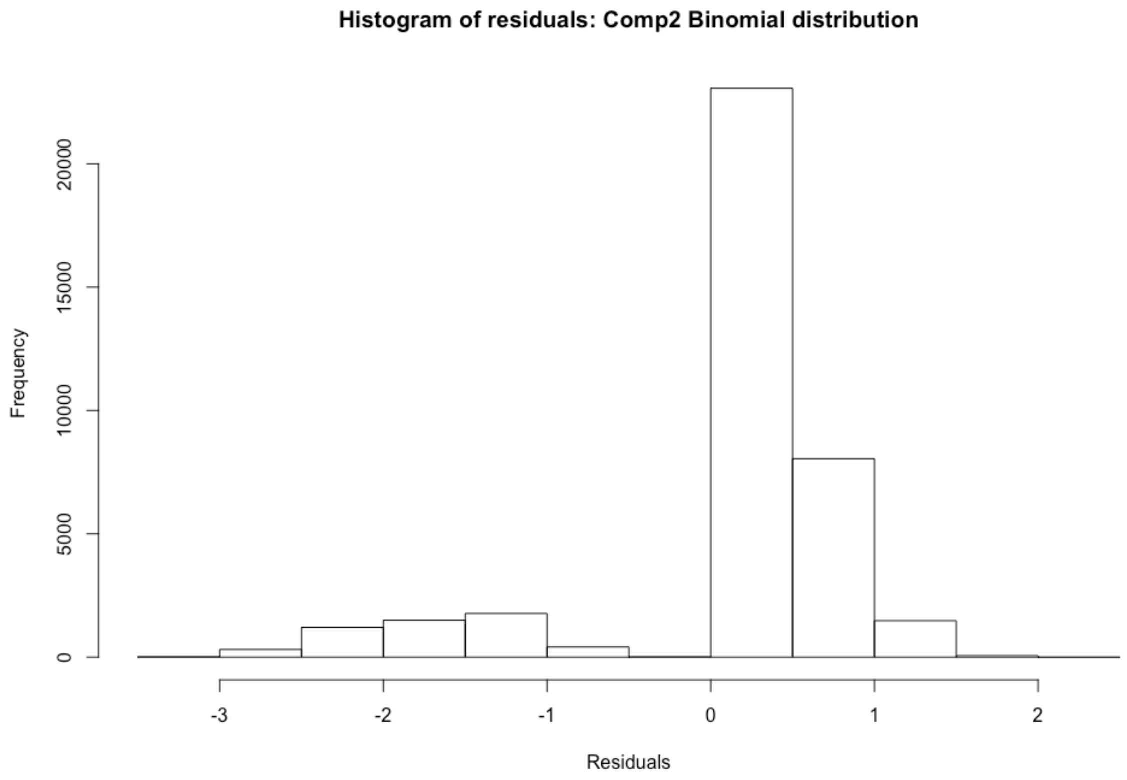

Figure 8. FSC sets – fraction of positive set with large YFT: histogram of residuals

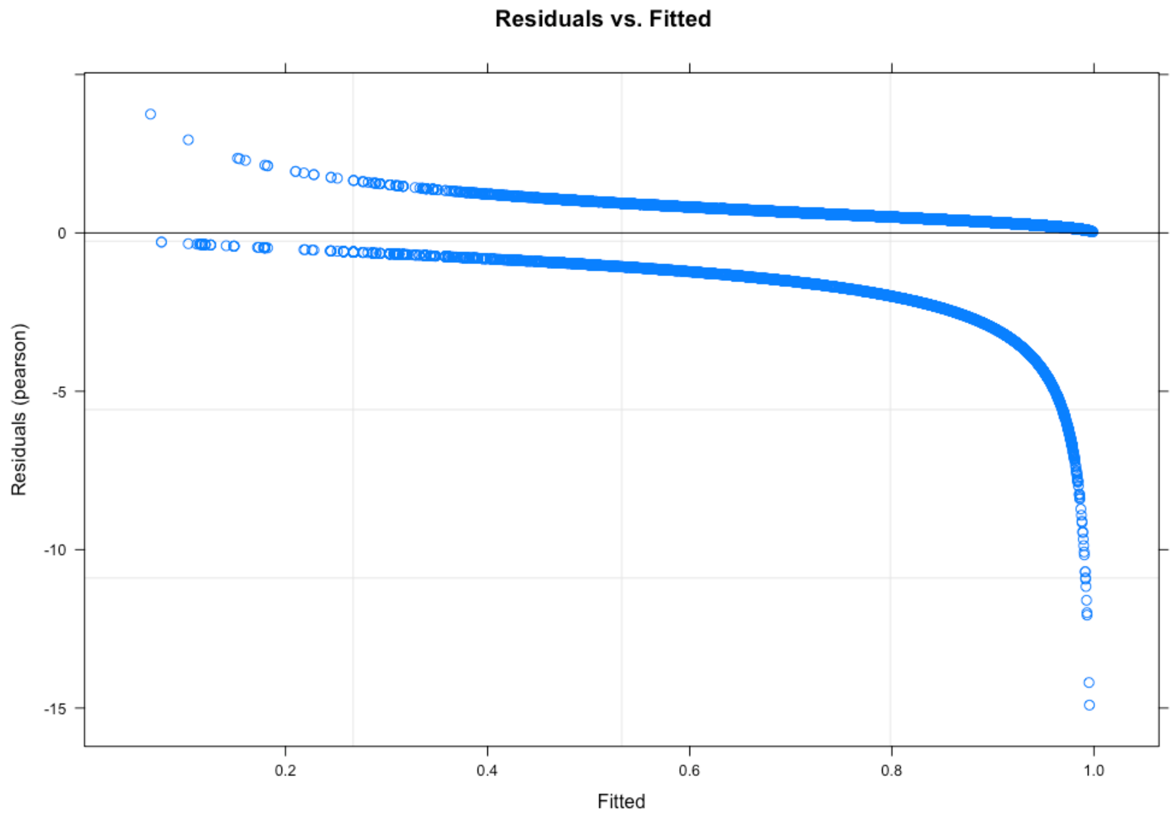

Figure 9. FSC sets – fraction of positive set with large YFT: residuals versus fitted

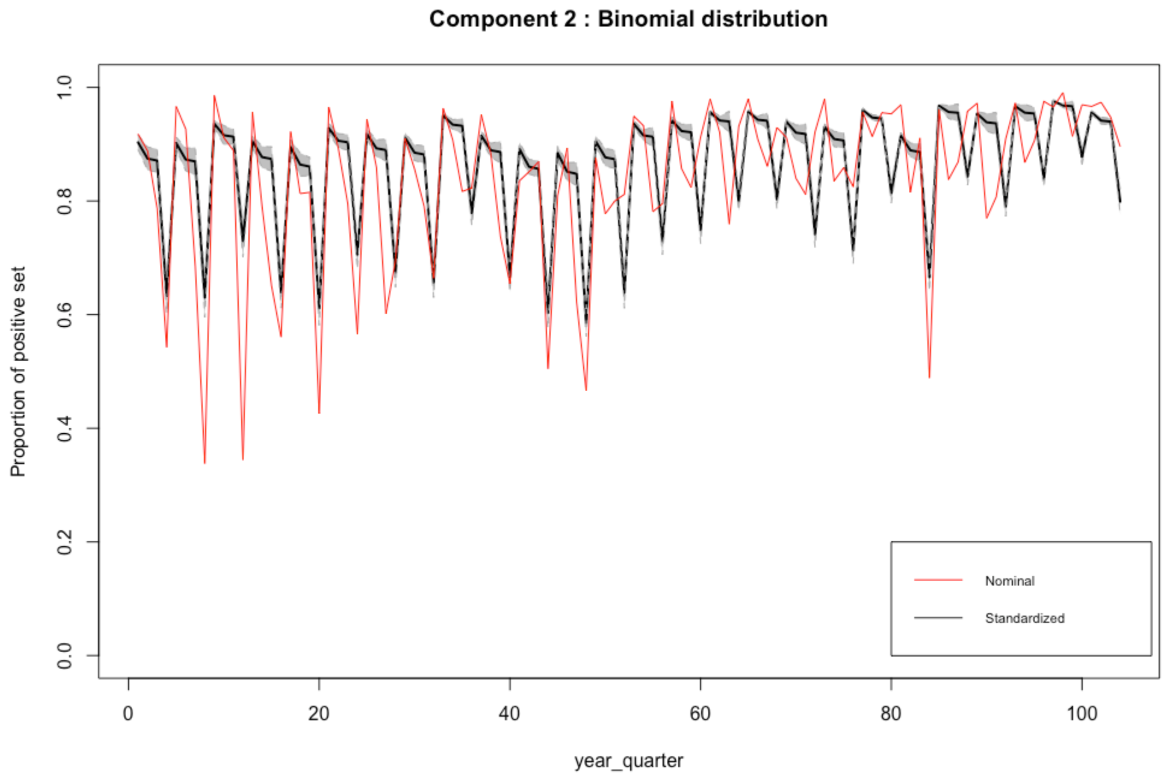

Figure 10. FSC sets – fraction of positive set with large YFT: standardised time series by year-quarter (black) with 97.5% confidence intervals (grey) compared to nominal (red)

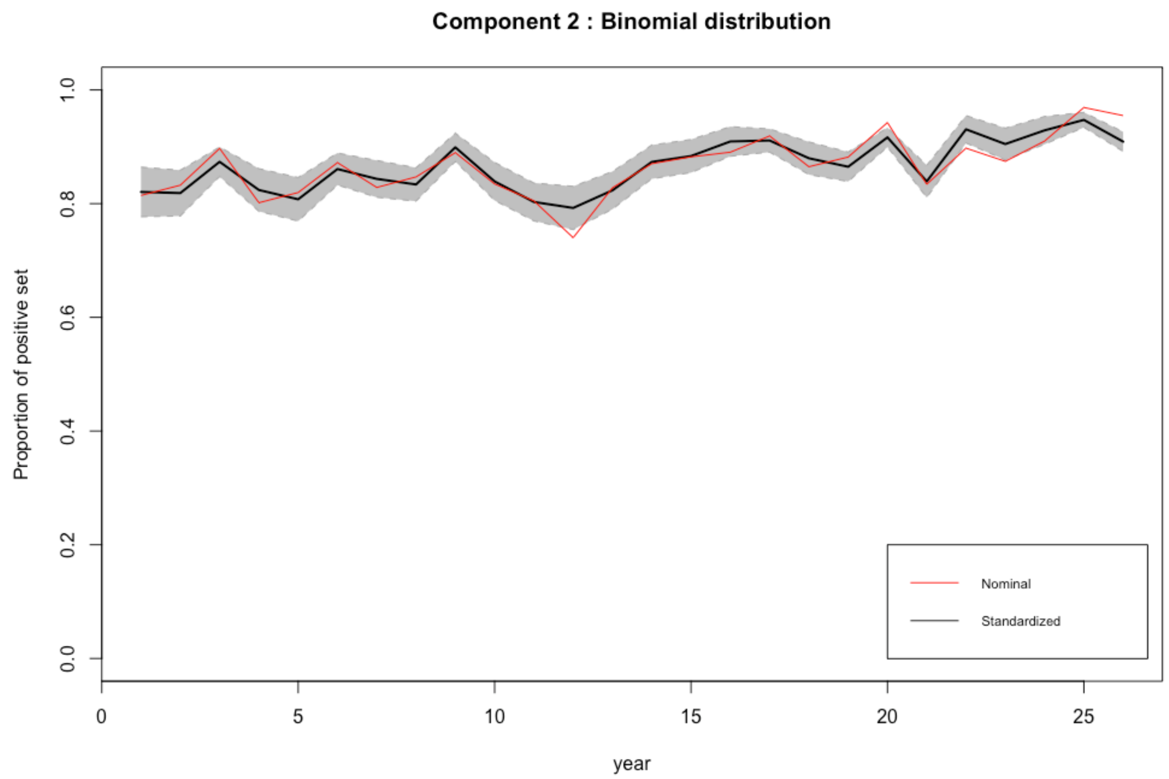

Figure 11. FSC sets – fraction of positive set with large YFT: standardised time series by year (black) with 97.5% confidence intervals (grey) compared to nominal (red)

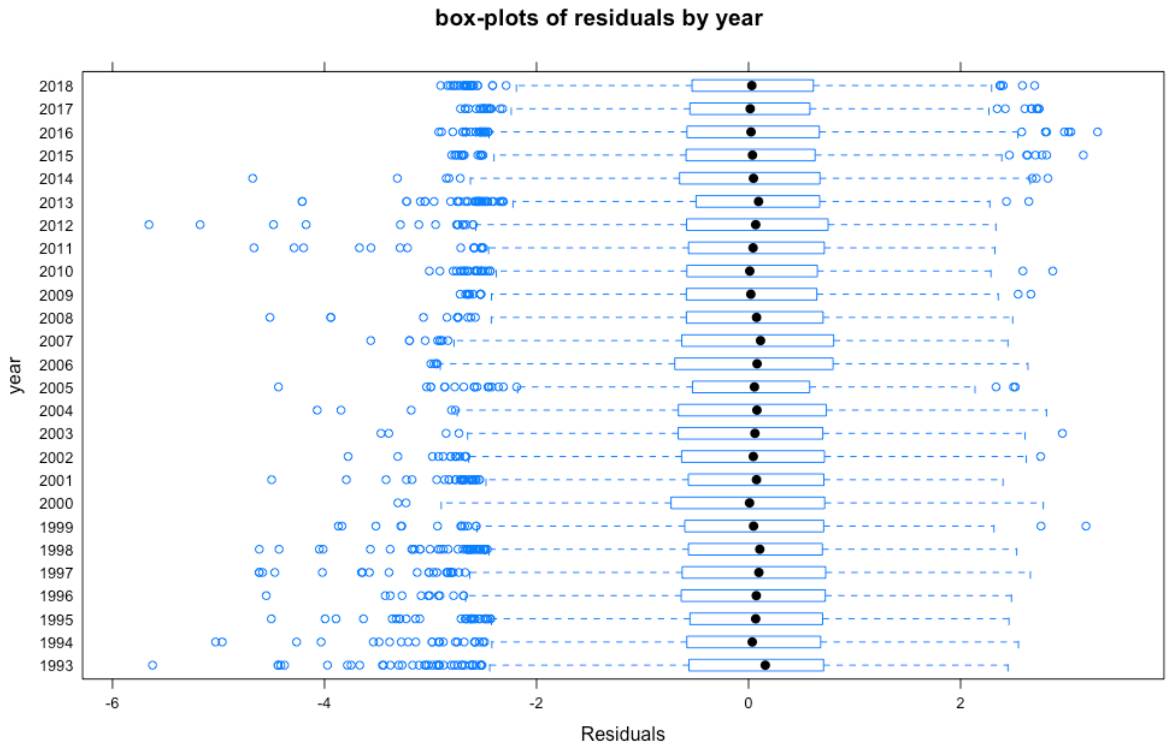

Figure 12. FSC sets – catch | catch > 0 with large YFT: box-plots of residuals by year.

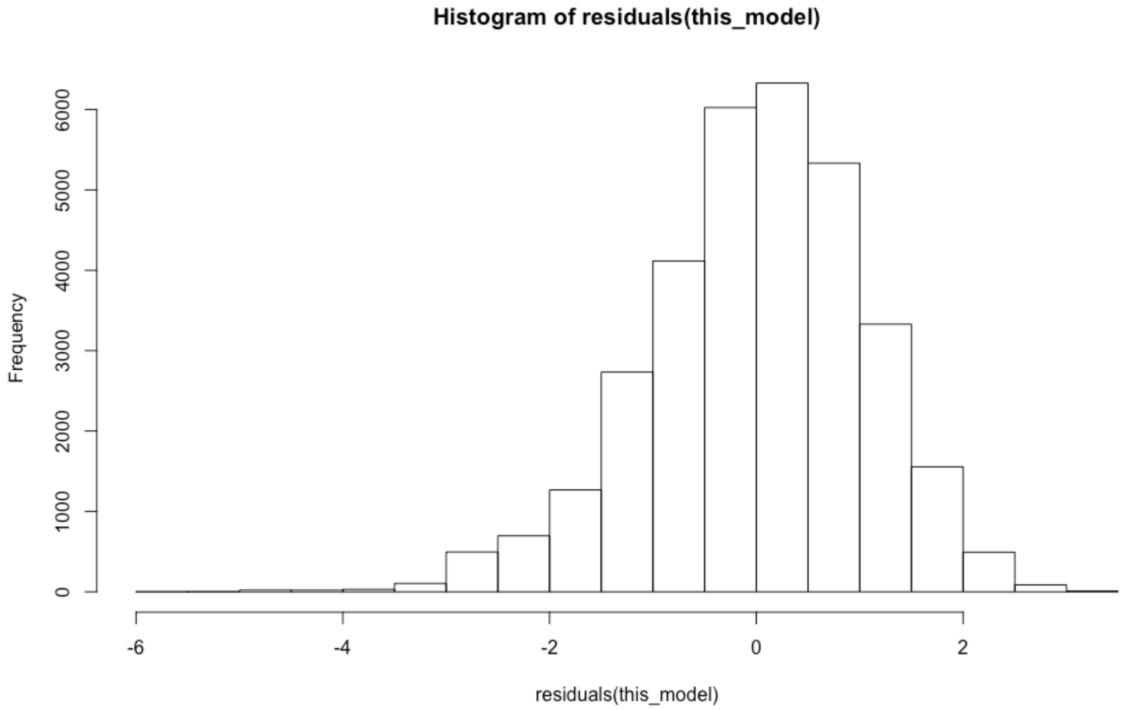

Figure 13. FSC sets – catch | catch > 0 with large YFT: histogram of residuals.

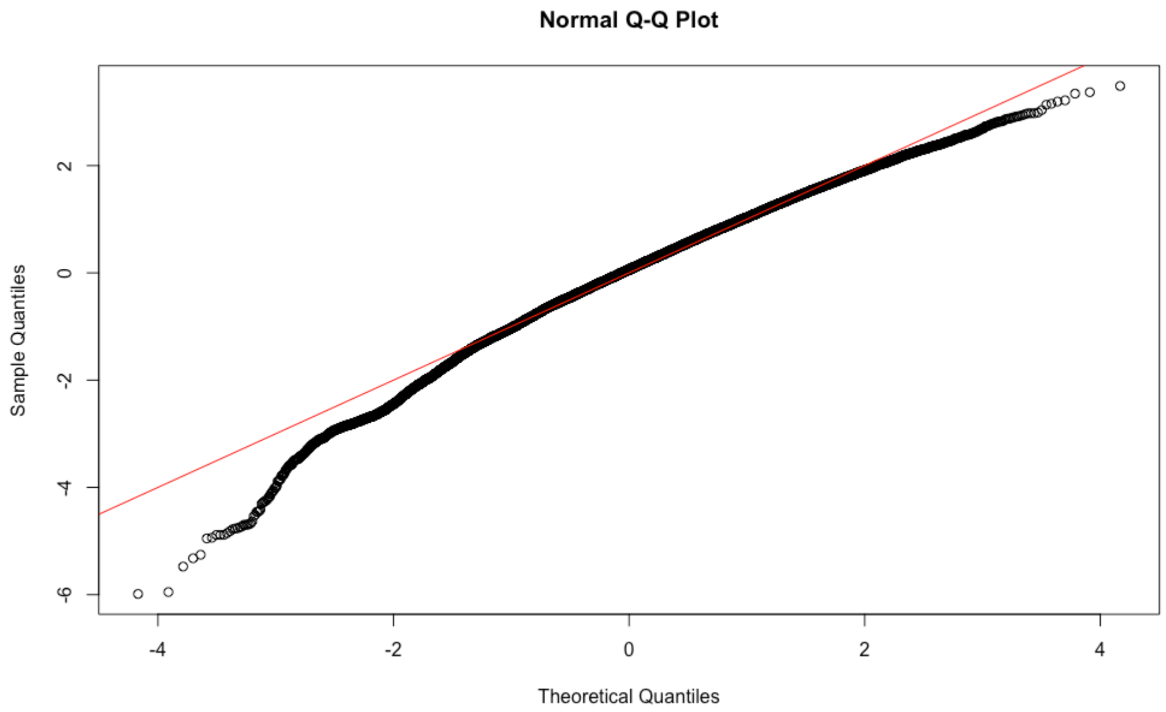

Figure 14. FSC sets – catch | catch > 0 with large YFT: normal Q-Q plot.

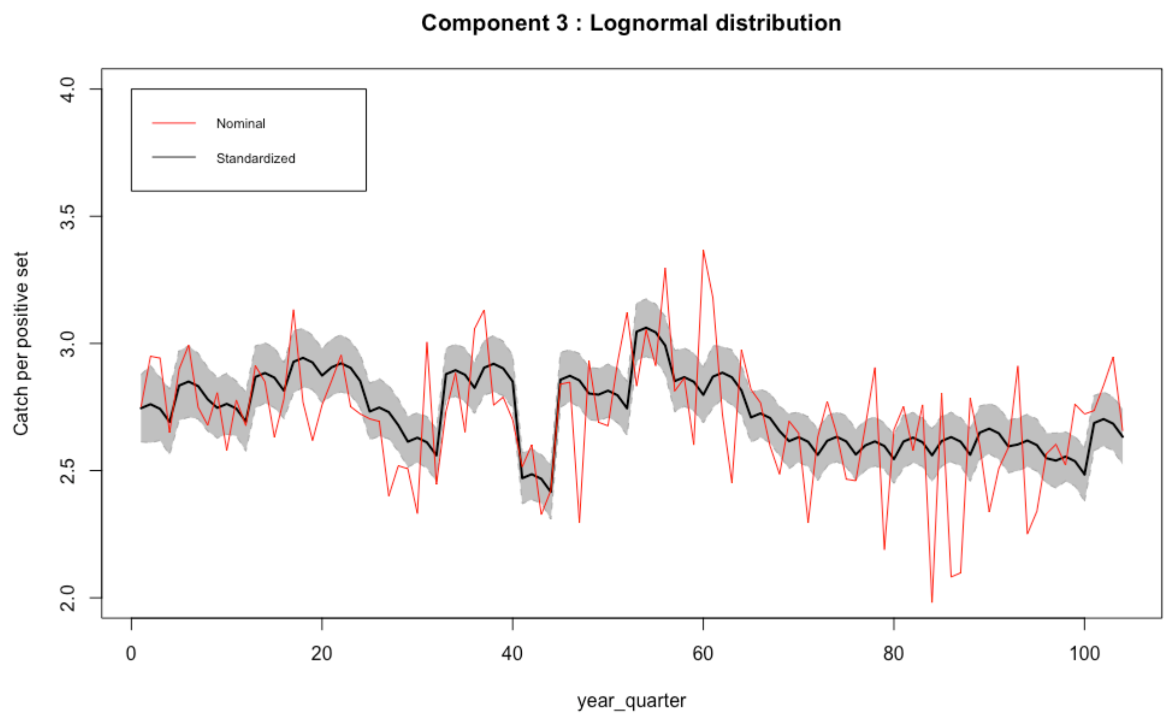

Figure 15. FSC sets – catch | catch > 0 with large YFT: standardised time series by year-quarter (black) with 97.5% confidence intervals (grey) compared to nominal (red)

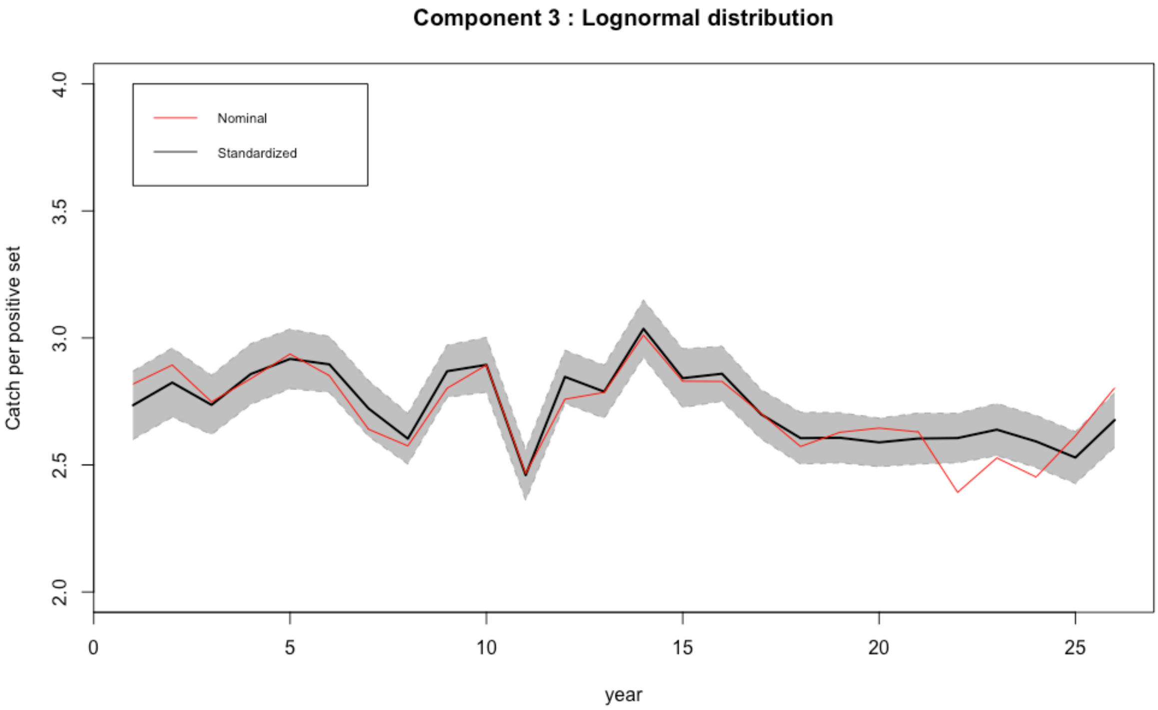

Figure 16. FSC sets – catch | catch > 0 with large YFT: standardised time series by year (black) with 97.5% confidence intervals (grey) compared to nominal (red)

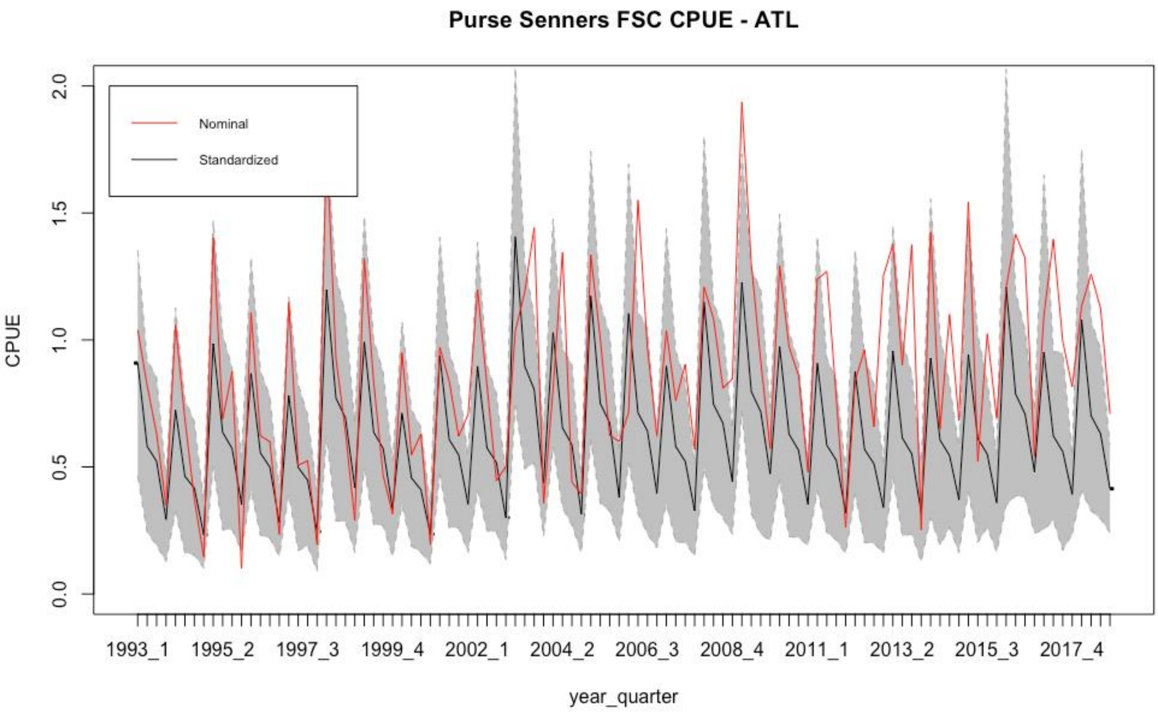

Figure 17. Standardised CPUE for free school sets of yellowfin tuna category 2 & 3 (black line), with 97.5% CIs (grey,) and compared to nominal CPUE (red). Time series on a quarter basis.

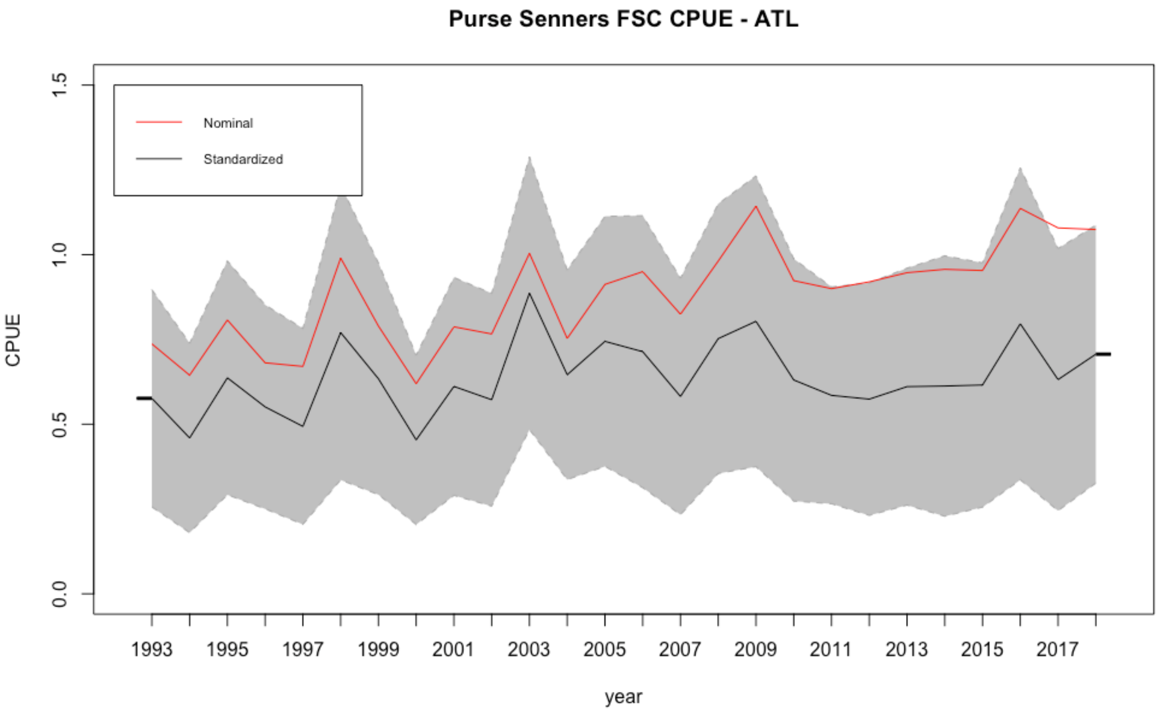

Figure 18. Standardised CPUE for free school sets of yellowfin tuna category 2 & 3 (black line), with 97.5% CIs (grey,) and compared to nominal CPUE (red). Time series on an annual basis

APPENDICES

DATA PER YEAR-QUARTER

Year_quarter	Stand CPUE	Lower stand CPUE (IC97.5)	Upper stand CPUE (IC97.5)	SE CPUE	SD	CV
1993_1	0,909029727	0,46487961	1,353179844	0,198281302	10,5463778	11,60179639
1993_2	0,5812665	0,24221726	0,92031574	0,151361268	6,229714844	10,71748474
1993_3	0,522120787	0,19148761	0,852753964	0,147604097	6,433104681	12,32110432
1993_4	0,292985377	0,12744986	0,458520893	0,073899784	3,205263727	10,94001265
1994_1	0,725098509	0,324152388	1,12604463	0,178993804	9,951548411	13,72440887
1994_2	0,463370305	0,162314074	0,764426536	0,134400103	5,867466424	12,66258618
1994_3	0,416284347	0,152618286	0,679950409	0,117708063	4,431739501	10,64594316
1994_4	0,232854916	0,102435696	0,363274136	0,058222866	2,503424571	10,75100589
1995_1	0,985247347	0,500180826	1,470313869	0,216547554	11,16848577	11,33571768
1995_2	0,63639106	0,25135098	1,02143114	0,171892893	7,593371667	11,93192699
1995_3	0,572318987	0,253852694	0,89078528	0,142172452	5,69384139	9,948720068
1995_4	0,353179685	0,168257584	0,538101787	0,08255451	3,701505085	10,48051527
1996_1	0,86808857	0,408170906	1,328006234	0,205320386	10,77772323	12,41546497
1996_2	0,555301507	0,231702384	0,878900629	0,144463894	6,458116564	11,62992804
1996_3	0,498973061	0,218364176	0,779581945	0,125271823	4,973640041	9,967752638
1996_4	0,281887201	0,148253213	0,41552119	0,059658031	2,651068836	9,404715166
1997_1	0,782002962	0,394785003	1,16922092	0,17286516	8,608813368	11,00867105
1997_2	0,49851518	0,171060772	0,825969588	0,146185004	6,162920571	12,36255348
1997_3	0,447827599	0,189598025	0,706057174	0,11528106	4,013413974	8,961962105
1997_4	0,245646828	0,089983132	0,401310524	0,069492722	2,582180979	10,51176195
1998_1	1,197266529	0,620122392	1,774410665	0,257653632	12,17629102	10,17007552
1998_2	0,771251076	0,287871147	1,254631005	0,215794611	8,761711067	11,36038748
1998_3	0,693652427	0,284248976	1,103055877	0,182769398	6,497827469	9,367555307
1998_4	0,418792162	0,164217618	0,673366706	0,11364935	4,547631003	10,858921
1999_1	0,991792875	0,494774352	1,488811399	0,22188327	9,91487945	9,996925463
1999_2	0,63707026	0,272902549	1,001237972	0,162574871	6,017113878	9,444976878
1999_3	0,572532954	0,269650609	0,8754153	0,135215333	5,029212249	8,784144583
1999_4	0,334872282	0,145922563	0,523822	0,084352553	3,155823574	9,423961753
2000_1	0,712308898	0,351172741	1,073445056	0,161221499	7,244020384	10,16977382
2000_2	0,456820069	0,188092553	0,725547585	0,119967641	4,652937018	10,1854917
2000_3	0,41033221	0,163767155	0,656897264	0,110073685	4,300074207	10,47949468
2000_4	0,235652743	0,118440123	0,352865363	0,052327063	1,900332656	8,064122808
2001_1	0,93728082	0,470004974	1,404556666	0,208605288	9,178560194	9,792753675
2001_2	0,607945777	0,260929409	0,954962145	0,154918021	5,561899161	9,148676367
2001_3	0,547188159	0,260240435	0,834135882	0,128101662	5,486987882	10,02760713
2001_4	0,353231977	0,16500301	0,541460944	0,084030789	3,306555297	9,360860599
2002_1	0,896360186	0,408101403	1,384618969	0,217972671	9,280808098	10,35388256
2002_2	0,575043232	0,248190951	0,901895513	0,145916197	5,712576613	9,934168937
2002_3	0,516932386	0,243591376	0,790273396	0,122027237	4,452148511	8,612632198
2002_4	0,300171187	0,136210049	0,464132324	0,073196936	2,764109603	9,208444137
2003_1	1,407118795	0,741000973	2,073236617	0,297374028	12,80915356	9,10310743
2003_2	0,897209882	0,491735631	1,302684134	0,181015291	6,537506874	7,286485584
2003_3	0,805007423	0,515756695	1,094258151	0,129129789	4,590608951	5,702567231
2003_4	0,436770668	0,226317631	0,647223705	0,093952249	3,334322444	7,63403472
2004_1	1,029088829	0,580846622	1,477331036	0,200108128	8,254110789	8,020795245
2004_2	0,65404561	0,339596211	0,968495009	0,140379196	4,875992045	7,455125407
2004_3	0,587237638	0,270493044	0,903982231	0,141403836	4,879255705	8,308826604
2004_4	0,313162682	0,162224989	0,464100375	0,067382899	2,2146542	7,071896898
2005_1	1,172707557	0,603892637	1,741522478	0,253935232	8,574613826	7,311809131
2005_2	0,750195852	0,356770335	1,143621368	0,175636391	4,806102981	6,406464352
2005_3	0,673987074	0,326602024	1,021372124	0,155082612	4,694210961	6,964838263

2005_4	0,38023697	0,204655599	0,555818342	0,078384541	2,303926406	6,059185681
2006_1	1,1046606	0,517210451	1,692110749	0,262254531	7,978518862	7,222597476
2006_2	0,713018344	0,316300845	1,109735844	0,177106026	4,927399907	6,910621509
2006_3	0,641629579	0,235898475	1,047360682	0,181129957	4,69692343	7,32030378
2006_4	0,396275818	0,181860957	0,610690679	0,09572092	2,594039395	6,546045144
2007_1	0,896911891	0,355148854	1,438674927	0,241858498	7,086069981	7,90051961
2007_2	0,580240242	0,203929025	0,956551459	0,167996079	4,992496267	8,604188243
2007_3	0,522055585	0,203160427	0,840950744	0,14236391	4,364195513	8,359637624
2007_4	0,328097508	0,148139869	0,508055148	0,080338232	2,19745133	6,697555677
2008_1	1,149116865	0,495158247	1,803075484	0,291945812	9,457759395	8,230459129
2008_2	0,746681367	0,34502945	1,148333285	0,179308892	5,807232504	7,77739041
2008_3	0,672184987	0,299520253	1,044849722	0,166368185	5,487262026	8,163321302
2008_4	0,441709494	0,235534524	0,647884464	0,092042397	3,052652321	6,910995494
2009_1	1,226334801	0,71908595	1,733583652	0,22645038	7,915649926	6,454721761
2009_2	0,797380605	0,316583297	1,278177913	0,214641655	7,738807536	9,705286891
2009_3	0,717590456	0,23514246	1,200038452	0,21537857	8,987906017	12,52511923
2009_4	0,472582033	0,21097175	0,734192315	0,116790305	4,238991552	8,969853399
2010_1	0,973257478	0,449982659	1,496532297	0,23360483	9,280540625	9,535545148
2010_2	0,629559916	0,225207383	1,033912449	0,180514524	7,128745945	11,32337966
2010_3	0,566069914	0,22252885	0,909610979	0,153366547	5,690464187	10,05258192
2010_4	0,352941849	0,190674321	0,515209377	0,072440861	2,552058579	7,230818859
2011_1	0,908077235	0,407211959	1,40894251	0,223600569	7,671431894	8,44799495
2011_2	0,585810434	0,241969988	0,929650881	0,153500199	5,716134017	9,757651419
2011_3	0,52656676	0,212219902	0,840913618	0,140333419	5,096316585	9,678386431
2011_4	0,319771658	0,159483246	0,480060069	0,071557326	2,45244685	7,669369038
2012_1	0,874266398	0,393385573	1,355147224	0,21467894	8,08035431	9,242439518
2012_2	0,569141729	0,202555019	0,935728439	0,163654781	6,011897771	10,56309433
2012_3	0,512105027	0,199092238	0,825117815	0,139737852	4,43275415	8,655947352
2012_4	0,340247858	0,160811344	0,519684373	0,080105587	2,48155799	7,293383129
2013_1	0,956922818	0,461749505	1,452096131	0,221059515	7,195115869	7,519013798
2013_2	0,614330613	0,22802078	1,000640447	0,172459747	6,060231249	9,864771698
2013_3	0,551881717	0,235953309	0,867810125	0,141039468	3,460714789	6,270754553
2013_4	0,320004004	0,125886165	0,514121843	0,08665975	2,591640499	8,098775219
2014_1	0,928313019	0,301300006	1,555326031	0,279916523	8,449775273	9,102291039
2014_2	0,605705534	0,191000837	1,02041023	0,185136025	5,972271764	9,860025098
2014_3	0,545178609	0,262158378	0,82819884	0,126348317	3,810058499	6,988642684
2014_4	0,37108584	0,162442395	0,579729285	0,093144395	2,557223211	6,891190488
2015_1	0,941833889	0,403172424	1,480495353	0,240473868	8,21430657	8,721608628
2015_2	0,611836985	0,203192851	1,020481119	0,182430417	6,280800485	10,26548025
2015_3	0,550463448	0,262220894	0,838706003	0,128679712	4,233034692	7,689946907
2015_4	0,358525271	0,164468466	0,552582077	0,086632502	2,562613037	7,147649669
2016_1	1,207327847	0,348244032	2,066411663	0,38351956	12,53125222	10,3793284
2016_2	0,787548909	0,38698793	1,188109887	0,178821865	5,81634306	7,385373781
2016_3	0,708800861	0,378840005	1,038761717	0,147303954	4,684784507	6,609450925
2016_4	0,480919613	0,238647995	0,72319123	0,108156972	3,197339659	6,648386912
2017_1	0,951326833	0,253331764	1,649321902	0,311604942	9,998814142	10,51038801
2017_2	0,622479487	0,289857963	0,955101011	0,148491752	4,620538822	7,422796926
2017_3	0,560336466	0,172007348	0,948665583	0,173361213	3,859057555	6,887036258
2017_4	0,391987625	0,236452412	0,547522838	0,069435363	2,248931879	5,737252244
2018_1	1,079103408	0,40576375	1,752443066	0,300598062	8,600728727	7,970254439
2018_2	0,70144717	0,327325916	1,075568424	0,167018417	5,568842394	7,939076004
2018_3	0,631197183	0,296202253	0,966192113	0,149551308	3,775216717	5,981041768
2018_4	0,414195554	0,241144125	0,587246983	0,077255102	2,184808618	5,274823923

DATA PER YEAR

Year	Stand CPUE	Lower stand CPUE (IC97.5)	Upper stand CPUE (IC97.5)	SE CPUE	SD	CV (%)
1993	0,576350598	0,255854443	0,896846752	0,14307864	13,06838997	22,67437568
1994	0,459402019	0,180018812	0,738785227	0,124724646	11,38420871	24,7804934
1995	0,63678427	0,29183234	0,9817362	0,153996397	14,00757094	21,99735703
1996	0,551062584	0,250247847	0,851877322	0,134292294	12,28178128	22,28745268
1997	0,493498142	0,204618992	0,782377292	0,128963906	10,69434853	21,67049399
1998	0,770240548	0,335621362	1,204859735	0,194026423	15,95774558	20,71787264
1999	0,634067093	0,292195644	0,975938542	0,152621183	11,99007762	18,90979323
2000	0,45377848	0,204216828	0,703340131	0,111411452	8,91401345	19,64397574
2001	0,611411683	0,290009801	0,932813565	0,143482983	11,67465427	19,09458814
2002	0,572126748	0,258350928	0,885902567	0,140078491	10,96133617	19,15892977
2003	0,886526692	0,484171017	1,288882367	0,179623069	13,5825788	15,32111658
2004	0,64588369	0,336595583	0,955171797	0,138075048	9,953502057	15,41067256
2005	0,744281863	0,375549046	1,113014681	0,164612865	10,00394049	13,44106444
2006	0,713896085	0,312840952	1,114951218	0,17904247	9,989466145	13,99288545
2007	0,581826307	0,233036626	0,930615988	0,155709679	9,128170585	15,68882411
2008	0,752423178	0,354702883	1,150143474	0,177553703	11,63147331	15,45868554
2009	0,803471974	0,374759156	1,232184791	0,191389651	14,30363146	17,80227802
2010	0,630457289	0,273187657	0,987726922	0,159495372	12,12158534	19,22665586
2011	0,585056522	0,265361376	0,904751667	0,142721047	10,16854735	17,38045296
2012	0,573940253	0,231070795	0,916809712	0,153066723	10,53393847	18,3537196
2013	0,610784788	0,261377123	0,960192453	0,155985565	9,615308662	15,7425477
2014	0,61257075	0,228534709	0,996606792	0,171444661	10,31330108	16,83609782
2015	0,615664898	0,255403303	0,975926493	0,160831069	10,56537749	17,16092231
2016	0,796149307	0,335960979	1,256337636	0,205441218	13,01832711	16,35161519
2017	0,631532603	0,244844696	1,018220509	0,17262853	10,29074109	16,2948691
2018	0,706485829	0,325995312	1,086976346	0,169861838	9,877856262	13,98167643

COEFFICIENTS OF THE COMPONENT 1 (POISSON DISTRIBUTION)

Generalized linear mixed model fit by maximum likelihood (Laplace Approximation) ['glmerMod']
Family: poisson (log)
Formula: num_sets_fsc ~ pays + age + num_sets_fob + cap_m3 + yr + quarter + cwp55_group + (1 | c_bat) + (1 | eez_iso_3digit:fishing_access) + offset(searching_centroid)
Data: D
Control: glmerControl(optimizer = "bobyqa". optCtrl = list(maxfun = 30000))

AIC	**BIC**	**logLik**	**deviance**	**df.resid**
404293.8	404708.3	-202104.9	404209.8	142525

Scaled residuals:

Min	1Q	Median	3Q	Max
-1.870	-0.698	-0.474	-0.052	174.270

Random effects:

Groups	Name	Variance	Std.Dev.
c_bat	(Intercept)	0.1121	0.3348
eez_iso_3digit:fishing_access	(Intercept)	0.3601	0.6001

Number of obs: 142567, groups: c_bat, 87; eez_iso_3digit:fishing_access, 15

Fixed effects:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-1.072080907	0.176843861	-6.06230208	1.341869e-09	***
pays4	-0.189801654	0.079687002	-2.38183955	1.722640e-02	*
age	-0.064746717	0.038094804	-1.69962069	8.920230e-02	.
num_sets_fob	-0.177254812	0.009111582	-19.45379211	2.706552e-84	***
cap_m3	0.129685966	0.039630965	3.27233932	1.066615e-03	**
yr1994	-0.256442988	0.029192347	-8.78459638	1.569270e-18	***
yr1995	0.047392495	0.029206018	1.62269623	1.046544e-01	
yr1996	-0.091701513	0.031320657	-2.92782852	3.413382e-03	**
yr1997	-0.205556799	0.035180644	-5.84289465	5.130146e-09	***
yr1998	0.193656656	0.035609736	5.43830644	5.378940e-08	***
yr1999	0.077103126	0.039317829	1.96102196	4.987646e-02	*
yr2000	-0.203706372	0.043401602	-4.69352197	2.685411e-06	***
yr2001	-0.063324269	0.045737833	-1.38450521	1.662038e-01	
yr2002	-0.081850538	0.049568518	-1.65126057	9.868538e-02	.
yr2003	0.553455551	0.051659440	10.71354147	8.793229e-27	***
yr2004	0.103860519	0.057065819	1.82001277	6.875706e-02	.
yr2005	0.233765595	0.062266893	3.75425177	1.738600e-04	***
yr2006	0.248956424	0.067596931	3.68295453	2.305463e-04	***
yr2007	0.100272843	0.071324590	1.40586637	1.597638e-01	
yr2008	0.328231927	0.072959147	4.49884548	6.832349e-06	***
yr2009	0.449475247	0.075766830	5.93234855	2.986318e-09	***
yr2010	0.269922934	0.080003041	3.37390843	7.410901e-04	***
yr2011	0.208557647	0.084710498	2.46200474	1.381628e-02	*
yr2012	0.149577914	0.089151105	1.67780213	9.338573e-02	.
yr2013	0.277768163	0.093456387	2.97216885	2.957040e-03	**
yr2014	0.196121428	0.097550465	2.01046124	4.438239e-02	*
yr2015	0.211016574	0.101332739	2.08241261	3.730480e-02	*
yr2016	0.464945056	0.105049931	4.42594349	9.602166e-06	***
yr2017	0.242586935	0.109893897	2.20746503	2.728159e-02	*
yr2018	0.330815625	0.114321745	2.89372441	3.807021e-03	**
quarter2	-0.422755459	0.012765696	-33.11652324	1.718812e-240	***

quarter3	-0.519895122	0.013935797	-37.30644956	1.289951e-304	***
quarter4	-0.769331233	0.014100663	-54.55993241	0.000000e+00	***
cwp55_group200000	0.253899650	0.029379484	8.64207312	5.520208e-18	***
cwp55_group200005	-0.068924421	0.040883787	-1.68586194	9.182239e-02	.
cwp55_group300000	0.002686098	0.028979439	0.09268977	9.261500e-01	
cwp55_group300005	0.086213350	0.029963098	2.87731760	4.010717e-03	**
cwp55_group300010	0.124093539	0.032960753	3.76488792	1.666238e-04	***
cwp55_group400000_400010_400015_400020_405010_405015_405020	0.104595091	0.024123944	4.33573756	1.452722e-05	***
cwp55_group400005	-0.035312245	0.029781743	-1.18570108	2.357404e-01	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

COEFFICIENTS OF THE COMPONENT 2 (BINOMIAL DISTRIBUTION)

Generalized linear mixed model fit by maximum likelihood (Laplace Approximation) ['glmerMod']
Family: binomial (logit)
Formula: yft_pos ~ pays + cap_m3 + annee_de_peche + trimestre + cwp55_group +
(1 | numbat) + offset(nb_de_calees_pos)
Data: D
Control: glmerControl(optimizer = "bobyqa". optCtrl = list(maxfun = 30000))

AIC	**BIC**	**logLik**	**deviance**	**df.resid**
24824.8	25158.0	-12373.4	24746.8	37820

Scaled residuals:

Min	1Q	Median	3Q	Max
-14.9055	0.1519	0.2505	0.3672	3.7490

Random effects:

Groups	Name	Variance	Std.Dev.
numbat	(Intercept)	0.1403	0.3745

Number of obs: 37859, groups: numbat, 87

Fixed effects:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	1.28982330	0.12981074	9.9361835	2.897149e-23	***
pays4	-0.27076438	0.10078153	-2.6866468	7.217323e-03	**
cap_m3	0.13428634	0.04802376	2.7962482	5.169967e-03	**
annee_de_peche1994	-0.01606019	0.10543443	-0.1523240	8.789314e-01	
annee_de_peche1995	0.49076614	0.11206395	4.3793402	1.190392e-05	***
annee_de_peche1996	0.02787164	0.10132456	0.2750729	7.832602e-01	
annee_de_peche1997	-0.10287793	0.10620673	-0.9686574	3.327162e-01	
annee_de_peche1998	0.36005309	0.10301237	3.4952412	4.736335e-04	***
annee_de_peche1999	0.19680783	0.10239024	1.9221347	5.458881e-02	.
annee_de_peche2000	0.11023893	0.10720773	1.0282741	3.038209e-01	
annee_de_peche2001	0.78697927	0.11374296	6.9189273	4.550763e-12	***
annee_de_peche2002	0.15702101	0.10888805	1.4420408	1.492909e-01	
annee_de_peche2003	-0.13905435	0.09526523	-1.4596548	1.443850e-01	
annee_de_peche2004	-0.21793585	0.10008198	-2.1775733	2.943782e-02	*
annee_de_peche2005	0.02306325	0.11587249	0.1990399	8.422315e-01	
annee_de_peche2006	0.75883573	0.13776021	5.5083808	3.621493e-08	***
annee_de_peche2007	0.87295776	0.14236003	6.1320426	8.675786e-10	***
annee_de_peche2008	1.19606671	0.12574382	9.5119322	1.871535e-21	***
annee_de_peche2009	1.22014295	0.12020098	10.1508570	3.284663e-24	***
annee_de_peche2010	0.82914768	0.11434217	7.2514599	4.123031e-13	***
annee_de_peche2011	0.67115190	0.12402674	5.4113486	6.255186e-08	***
annee_de_peche2012	1.30039725	0.15004920	8.6664722	4.457154e-18	***
annee_de_peche2013	0.42745895	0.12598097	3.3930437	6.912060e-04	***
annee_de_peche2014	1.53099708	0.13229696	11.5724280	5.685069e-31	***
annee_de_peche2015	1.13345360	0.12296282	9.2178560	3.030998e-20	***
annee_de_peche2016	1.49876969	0.12922968	11.5977202	4.232022e-31	***
annee_de_peche2017	1.85944071	0.19461703	9.5543576	1.243530e-21	***
annee_de_peche2018	1.19152547	0.17749052	6.7131781	1.904304e-11	***
trimestre2	-0.32378974	0.05575536	-5.8073297	6.347708e-09	***
trimestre3	-0.35762902	0.06017581	-5.9430697	2.797333e-09	***
trimestre4	-1.87515388	0.05367977	-34.9322273	2.410775e-267	***
cwp55_group200000	0.40832597	0.10586413	3.8570759	1.147515e-04	***
cwp55_group200005	-2.02408941	0.08478916	-23.8720298	5.980911e-126	***

cwp55_group300000	0.81560938	0.12662523	6.4411285	1.185884e-10	***
cwp55_group300005	0.74520638	0.14017166	5.3163841	1.058496e-07	***
cwp55_group300010	0.49962512	0.14275686	3.4998326	4.655505e-04	***
cwp55_group400000_400010_400015_400020_405010_405015_405020	0.12472544	0.07965671	1.5657869	1.173985e-01	
cwp55_group400005	-0.05139896	0.09967738	-0.5156533	6.060966e-01	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

COEFFICIENTS OF THE COMPONENT 3 (LOGNORMAL DISTRIBUTION)

Linear mixed model fit by REML ['lmerMod']
Formula: log_capture ~ pays + cap_m3 + annee_de_peche + trimestre + cwp55_group + (1 | numbat) + offset(nb_de_calees_pos)
Data: D
Control: lmerControl(optimizer = "bobyqa". optCtrl = list(maxfun = 40000))

REML criterion at convergence: 96644.9

Scaled residuals:

Min	1Q	Median	3Q	Max
-5.6561	-0.5952	0.0582	0.6917	3.2926

Random effects:

Groups	Name	Variance	Std.Dev.
numbat	(Intercept)	0.02027	0.1424
Residual		1.12028	1.0584

Number of obs: 32643, groups: numbat, 87

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	1.897476	0.047624	39.843
pays4	-0.047961	0.037699	-1.272
cap_m3	0.111396	0.017164	6.490
annee_de_peche1994	0.089167	0.041984	2.124
annee_de_peche1995	0.001419	0.040294	0.035
annee_de_peche1996	0.122801	0.041904	2.931
annee_de_peche1997	0.182367	0.043582	4.184
annee_de_peche1998	0.160973	0.039412	4.084
annee_de_peche1999	-0.012917	0.041138	-0.314
annee_de_peche2000	-0.131595	0.042267	-3.113
annee_de_peche2001	0.133861	0.041645	3.214
annee_de_peche2002	0.159109	0.043660	3.644
annee_de_peche2003	-0.275222	0.039652	-6.941
annee_de_peche2004	0.111794	0.044428	2.516
annee_de_peche2005	0.053340	0.047245	1.129
annee_de_peche2006	0.348846	0.051726	6.744
annee_de_peche2007	0.154459	0.051057	3.025
annee_de_peche2008	0.171992	0.045374	3.791
annee_de_peche2009	0.011907	0.040969	0.291
annee_de_peche2010	-0.081539	0.043095	-1.892
annee_de_peche2011	-0.080024	0.044984	-1.779
annee_de_peche2012	-0.098272	0.045270	-2.171
annee_de_peche2013	-0.083165	0.047357	-1.756
annee_de_peche2014	-0.081199	0.046181	-1.758
annee_de_peche2015	-0.048117	0.044919	-1.071
annee_de_peche2016	-0.094693	0.044152	-2.145
annee_de_peche2017	-0.157964	0.046732	-3.380
annee_de_peche2018	-0.010351	0.048098	-0.215
trimestre2	0.015698	0.016723	0.939
trimestre3	-0.002505	0.018728	-0.134
trimestre4	-0.054006	0.020989	-2.573
cwp55_group200000	-0.189053	0.032865	-5.752
cwp55_group200005	-0.927750	0.031552	-29.404
cwp55_group300000	-0.168979	0.034742	-4.864
cwp55_group300005	-0.077207	0.037150	-2.078
cwp55_group300010	0.002495	0.041485	0.060
cwp55_group400000_400010_400015_400020_405010_405015_405020	-0.184061	0.026598	-6.920
cwp55_group400005	-0.157343	0.034088	-4.616